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Reference No. 53-85

Three Detailed Cross-Sections of the Gulf Stream

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In citing this manuscript in a bibliography, the reference should be followed by the phrase: UNPUBLISHED MANUSCRIPT

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Three Detailed Cross-Sections of the Gulf Stream

By

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Technical Report
Submitted to Geophysics Branch, Office of Naval Research
Under Contract N6onr-27701 (NR-083-004)

October 1953

APPROVED FOR DISTRIBUTION E. H. Smith
Director

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ABSTRACT

Three sections across the Gulf Stream in which deep temperature and salinity observations were made at close intervals show that comparably large values of surface current velocity are obtained from dynamic computations, the Geomagnetic-Electrokinetograph (G.E.K.) and from navigational data. The dynamic computations indicate that the crosscurrent slope of the isobaric surfaces is uneven, resulting theoretically in three or four zones of high velocity separated by zones of lower velocity. The navigational and GEK measurements do not clearly reflect this picture. It is suggested that the unevenness of the slopes of the isobaric surfaces is related to the surface temperature discontinuities observed in the Gulf Stream by von Arx and Richardson (1953) from aircraft, and that the Stream is composed of overlapping, discontinuous currents at all levels.

INTRODUCTION

With the advent of Loran and GEK equipment it became possible to measure the velocity of surface currents from a moving ship with some accuracy. In the Gulf Stream velocities of 4 to 5 knots (200-250 cm/sec) were normally found by Loran in the swiftest part of the current (Iselin and Fuglister 1948). Von Arx (1950) measured a peak velocity of 274 cm/sec with the GEK and values of more than 200 cm/sec are commonly observed with this instrument.

These velocities were in excess of those previously found by Dynamic Computations, a previous maximum being 140 cm/sec (Seiwell 1939, Fig. 19), in a typical section from Montauk Point to Bermuda. Iselin and Fuglister (1940) pointed out that values obtained by means of the geostrophic equation in the period 1931-1940 must be regarded as minimum values since the stations were usually too widely spaced to observe the true slopes of the isobaric surfaces. Also, with the navigational equipment available during that period it was impossible to tell at what angle to the Stream a section was made. If this angle were to deviate more than about

10° from the perpendicular a noticeable reduction in computed velocity would result, since the computations are concerned only with the component at right angles to the sections.

A cruise was made in the ATLANTIS in October and November 1950 in which the primary objective was to make sections across the Stream in which the slopes of the isobaric surfaces would be closely observed. This involved making hydrographic stations, consisting of serial observations of temperature and salinity, at closely spaced intervals across the current and at right angles to its axis. Without Loran, which enables the observer to fix the ship's position as frequently as he desires, this program could not have been attempted. It was planned to measure the surface current between stations with the GEK and Loran and to arrive at a proper basis for comparing the values obtained by these instruments with those computed from the temperature and salinity data.

The Sections

A preliminary survey was made to establish the location and curvature of the Stream. The results of this survey and the placings of the first two sections are shown in Figure 1. The contours of 200m temperature are usually considered an adequate index of the location of the Stream (Fuglister 1951). The placing of Section 1, stations 4842-4853, was decided on the basis of this survey. Section 2, stations 4853-4867, was made immediately afterwards on a reversed course since negligible changes in the position of the Stream had taken place between the time of the survey and the time when Section 1 was completed.

Four days elapsed before Section 3 was made and no time was available for another survey. Consequently the placing of Section 3 was decided on the basis of a single crossing of the Stream. This resulted in Section 3's not being made at right angles to the current since the Stream had meandered during the four days in a manner not recognized by the observers. Figure 2 shows the location of Section 3, the crossing (29-30 Oct.), on the basis of which the location was chosen, and the contours of 200m temperature before, during and after the section. GEK current direction data indicate that Section 1 deviated 2° from the perpendicular to the axis of the Stream, Section 2 four degrees and Section 3 sixteen degrees. (The axis of the Stream was considered to be the average direction of those GEK current

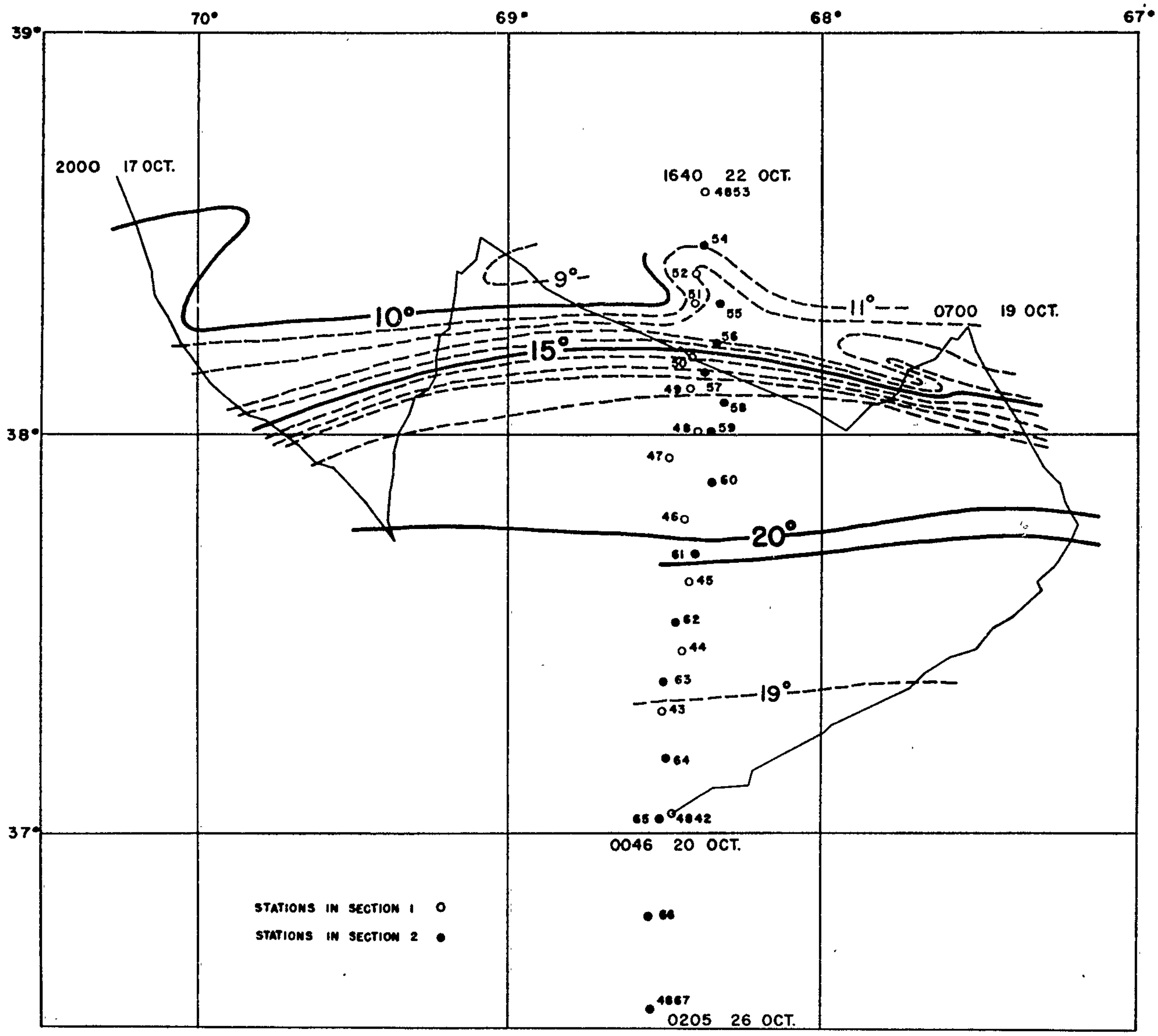

FIG. 1 TEMPERATURE AT 200 M. DURING PRELIMINARY SURVEY AND SECTION I

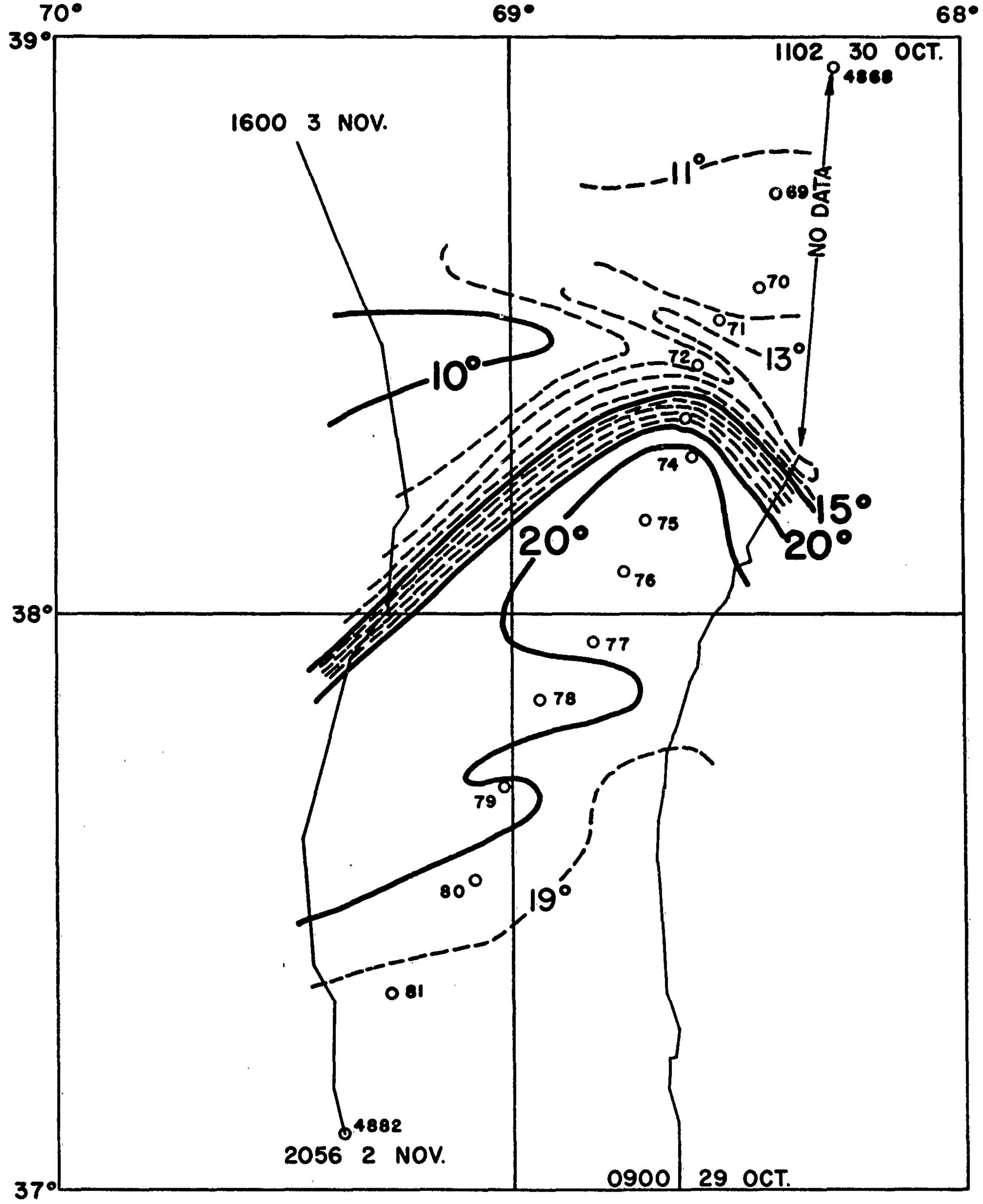

FIG. 2 TEMPERATURE AT 200 M. BEFORE, DURING, AND AFTER SECTION 3

fixes with velocities of more than 100 cm/sec in each section.)

The temperature profiles of the three sections are shown in Figures 3, 4 and 5, together with the distribution of the data, each dot representing an observation of temperature and salinity. Salinity profiles are not presented here since the T/S relationship was consistent, except in very shallow (0-200m) observations close to the inshore edge of the current.

In general two series of eleven Nansen bottles each were used, the shallow series from 1 to 900m and the deep from 1000 to 3200m by wire. Large wire angles were encountered, particularly in Section 1 where no efforts were made to reduce them by maneuvering the ship. In the second and third sections, where the ship was maneuvered, the bottles reached a depth of more than 2000m on all of the stations but one. Five unprotected thermometers were usually used with each series and much confidence is placed in the accuracy of the bottle-depth determinations.

The station positions given in Figures 1 and 2, and the times given in Figures 3, 4 and 5 are those of the shallow series which usually reached a depth of 600-800m. A Loran fix was obtained at the time the messenger was sent on each series. These sections are the most closely spaced available in the Gulf Stream, the usual distance between stations in the past having been about 20 nautical miles.

The Dynamic Computations

In all important particulars, the method of computation described by LaFond, 1951, has been used. The major source of inaccuracy in dynamic computations lies in the fact that small errors in position may give erroneously steep or gentle slopes to the isobaric surfaces, resulting in large errors in the computed currents. Von Arx (1952) has estimated that Loran fixes have an average error of 1 km., (about 0.5 nautical miles) in this area. Since Loran fixes were usually obtained at half-hourly intervals during these sections this error should give a scatter of ± 1 knot (about 100 cm/sec) in the values of current velocity obtained by this means. The observed scatter was considerably smaller than this which leads one to suspect that von Arx's estimate is pessimistic. However, in presenting the computed surface currents graphically (Figs. 6, 7 and 8) the effect of an 0.5 nautical miles error in the position of

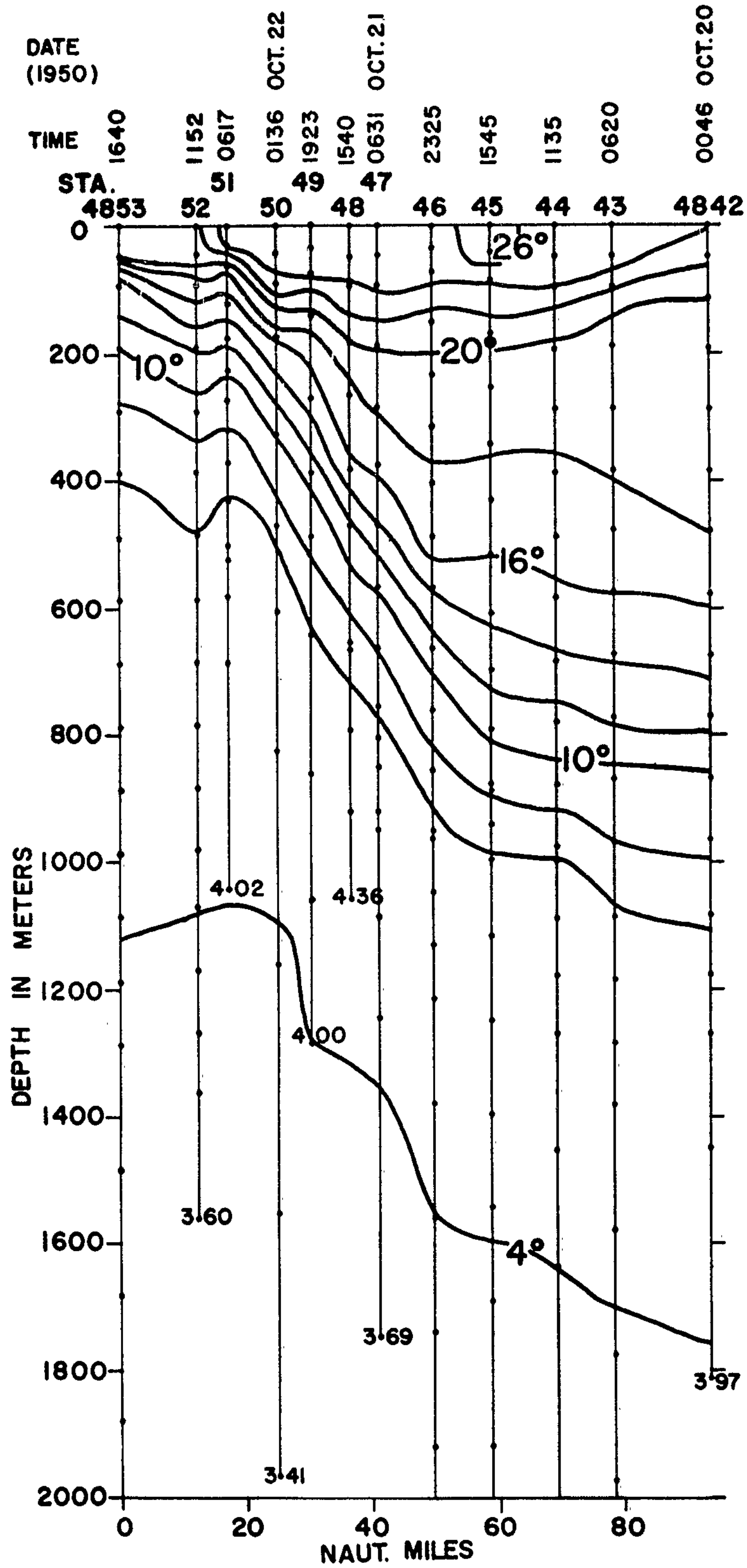

FIG. 3 SECTION I-TEMPERATURE

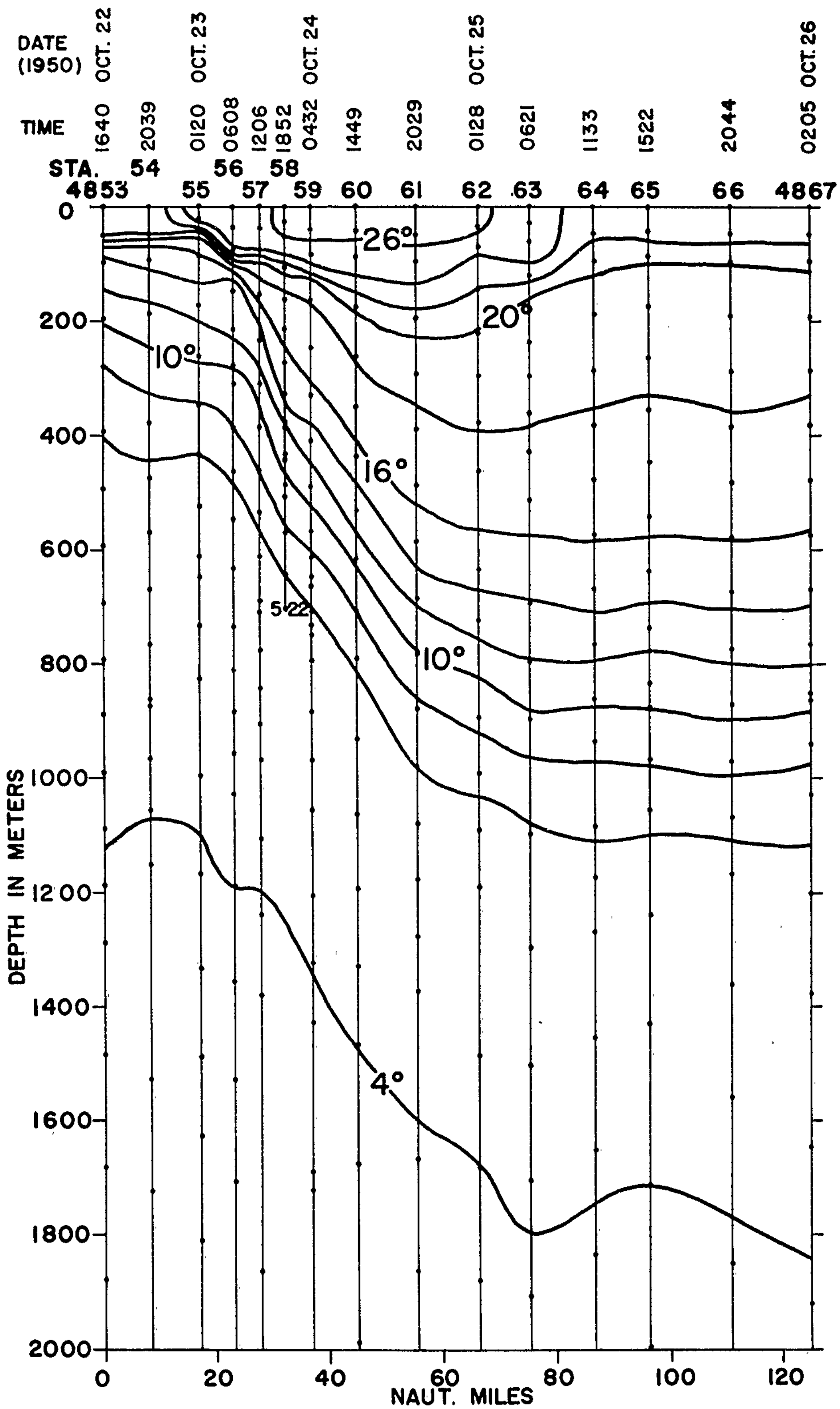

FIG. 4 SECTION 2– TEMPERATURE

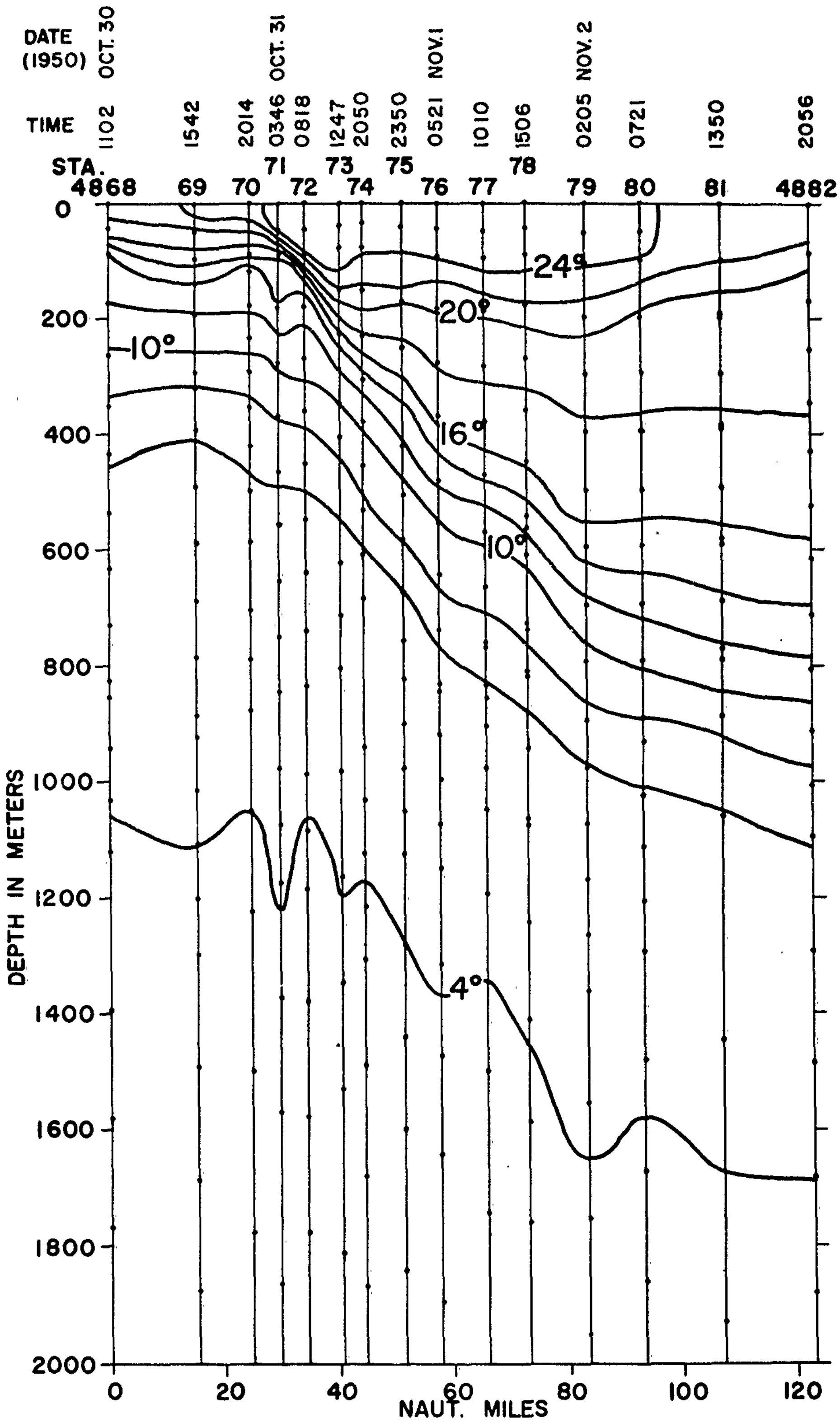

FIG. 5 SECTION 3 - TEMPERATURE

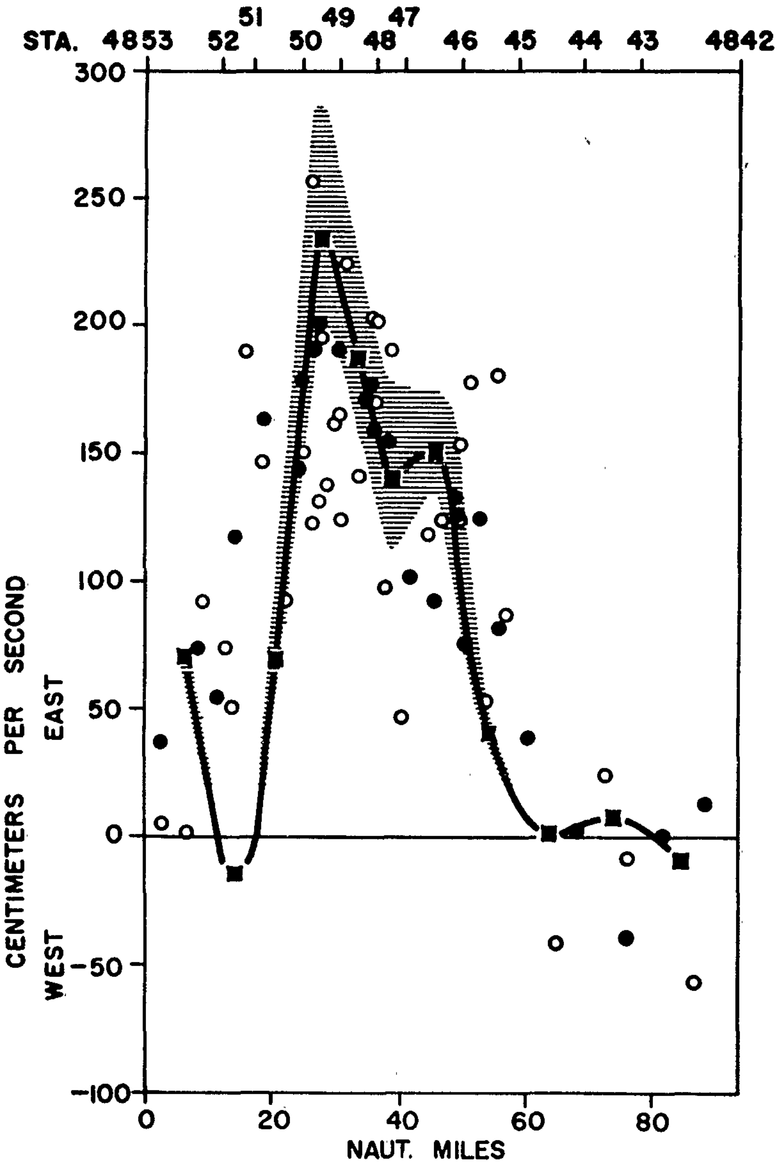

FIG. 6 SURFACE VELOCITY — SECTION I

The Following Symbols Apply to Figs: 6, 7, and 8

■ DYNAMIC CALCULATIONS
● GEK
○ LORAN

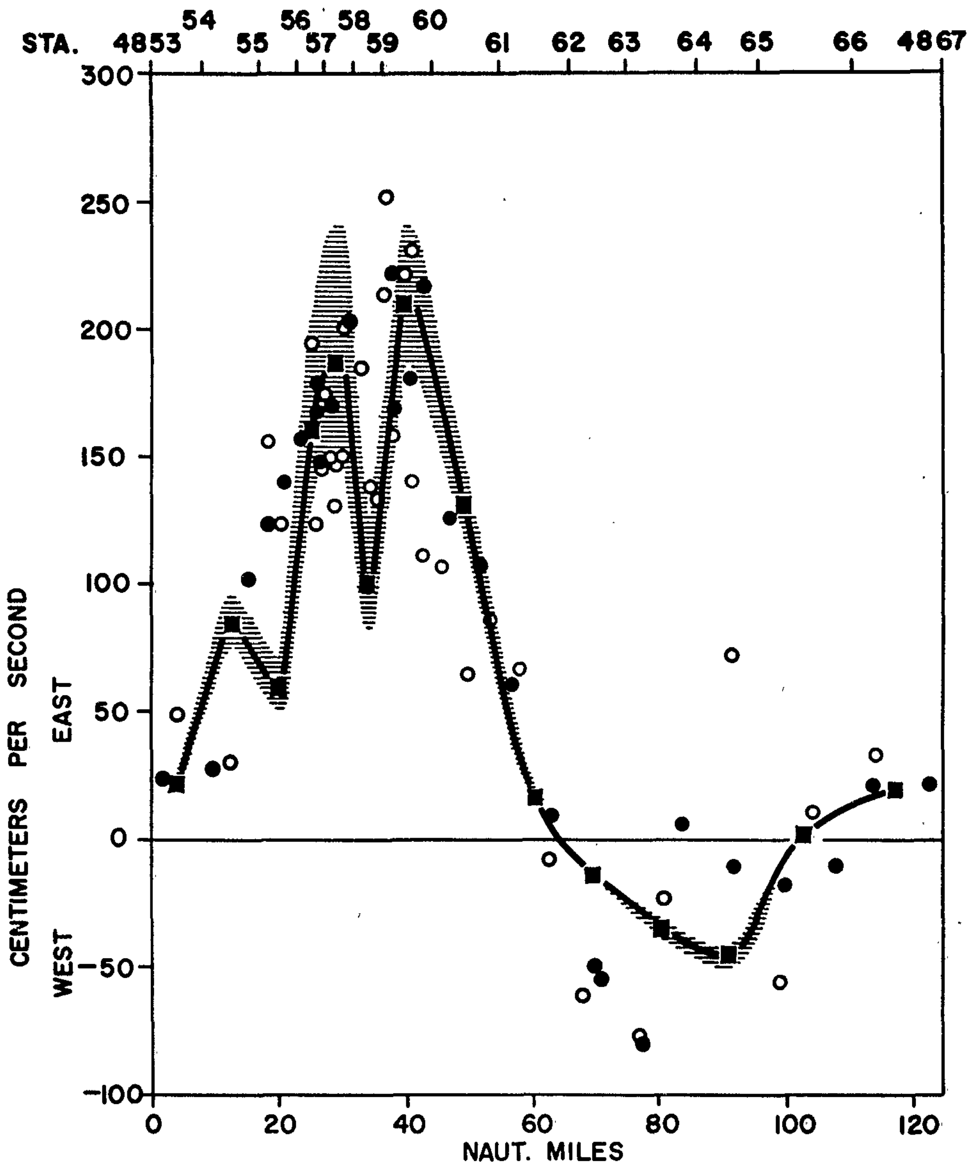

FIG. 7 SURFACE VELOCITY — SECTION 2

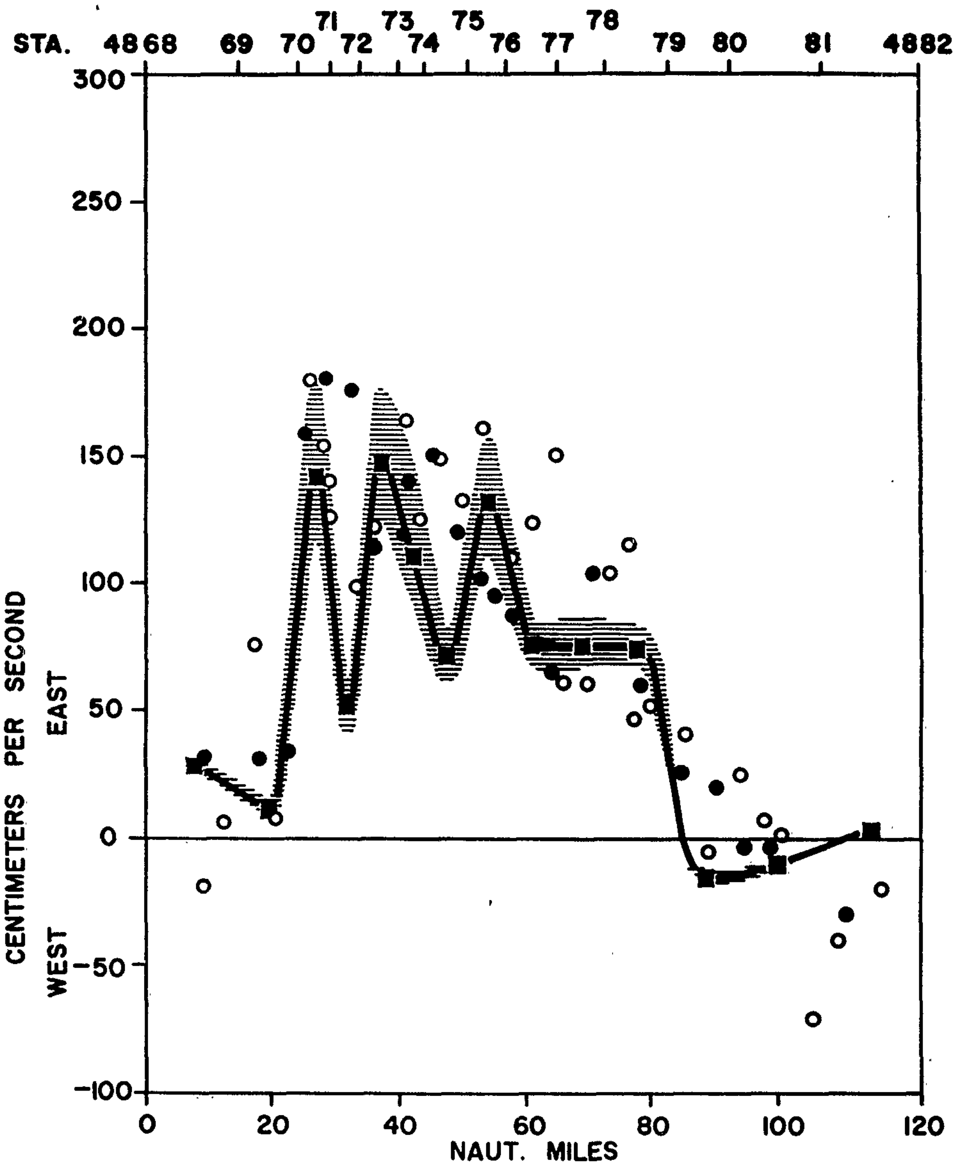

FIG. 8 SURFACE VELOCITY — SECTION 3

each station has been plotted as an envelope around the curves of surface velocity derived from the computations.

The true distances between stations were not used in all cases since many stations fell up or downstream from a mean line drawn through them. Instead it was assumed that all stations fell on the mean line.

The computed velocities are based on the assumption of a level of no motion at 2000m. This level was chosen because nearly all the stations extended to that depth, and the errors involved in the choice of this level are small. In Sections 2 and 3 data were available down to 3000m. These data show that a 5% increase in computed volume results if the 3000 decibar surface is assumed to be motionless instead of the 2000 decibar surface. Calculated velocities at 2000m referred to the 3000 decibar surface average, 3.5 cm/sec in Sections 2 and 3. This figure is approximate since the errors of salinity analysis (reckoned at ± 0.02 $^{o}/oo$) are critical at these depths.

Current Measurements by GEK

Current fixes were obtained with the GEK as frequently as time allowed when steaming between stations. The measured currents have been increased by a K factor of 1.2 (von Arx 1950). This K factor is an empirical factor based on hundreds of comparisons between currents measured with Loran and those measured with the GEK in the Gulf Stream, in which the GEK on average gives lower values than Loran.

More GEK measurements would have been desirable but they were sacrificed, perhaps too freely, in order that the ideal synoptic section might be more closely approached. About 25 measurements were made with each section.

Current Measurements by Loran

Loran fixes were obtained at half-hourly intervals when underway and the currents calculated according to the ship's displacement from its dead reckoning positions. The effect of wind drift was ignored. The errors in the Loran positions have been discussed above. About 35 current measurements were made with Loran in each section, and the component values at right angles to the sections used for comparison with the dynamic values.

The Comparisons

The three surface velocity profiles show that comparable values are found with all three methods of measurement, but the dynamic calculations indicate an unevenness of structure that is not clearly shown by the other two methods. To be sure, the Loran gives a more uneven picture if all the positions are assumed to be exact but the scatter of the Loran points is ascribed here, as elsewhere, to unavoidable errors in the system.

In all three sections the geostrophic equation consistently argues that the Stream is composed of bands of swift moving water separated by bands of relatively slow moving water. The navigational data are sufficiently accurate to ensure that large changes in the cross current slopes of the isobaric surfaces are real. What is not clear is whether or not there is a sufficiently close relationship between the slopes of the isobaric surfaces and the surface currents to warrant the assumption that the cross-current profile presented by the dynamic computations is more correct than those presented by Loran and GEK.

The dynamic computations ignore the effect of frictional forces which would tend to smooth out the unevenness required for a steady state. It is further possible that local winds and waves have a like effect on the surface layer. On the other hand the high scatter of the Loran measurements may obscure unevennesses in the currents that actually exist, and recent work by Longuet-Higgins, Stommel and Stern (not yet published) indicates that GEK values are influenced by the motion, or lack of motion, of water at some distance from the point of observation. The effect of this would certainly be toward averaging out the high and low velocity zones in these sections.

It is worthy of note that the existence of such high and low velocity zones was not suspected by the observers in the ship even though continuous temperature profiles were kept up as the station data came in. The changes in the slopes of the isotherms were regarded as negligible except in cases near the northern edge of the Stream where the slopes were actually reversed.

In retrospect, looking through past bathythermograph profiles across the stream where the 900 foot instrument was used, it was seen that changes in the slopes of the isotherms at the 200m level, comparable to the changes

found in these sections, are the rule rather than the exception. These bathythermograph data were obtained from ships continuously under way, which implies that the changes in slope found in these three sections cannot be attributed solely to the long time lapse between stations, and that comparable changes would have been found if all the stations in a section had been occupied simultaneously.

Subsurface Currents

From the computed velocity profiles illustrated in Figures 9, 10, and 11 it can be seen that the unevenness of the Stream is not confined to the surface layers. If the unevenness were due to errors in navigation one would expect that a high or low velocity zone would be found at all depths between the same pair of stations. In Figure 11 dashed lines have been drawn through the high and low zones, and it can be seen in many cases that a high zone at the surface is over a low zone at mid-depths.

In Section 3 (Fig. 11) the Stream appears to be divided into three parts, the two major parts being separated by a deep countercurrent. It is tempting to conclude that here the Gulf Stream is moving laterally across the countercurrent by re-forming to the north, and that the low velocity zones found further towards the southern edge of the Stream are the remnants of countercurrents which have been absorbed into the main current in the same manner, further upstream. Such crossings do not imply that Slope water is moving across the Stream but that changes in the slopes of the isobaric surfaces move slowly across the Stream in a manner analogous to wave motion.

Recent studies using aircraft (von Arx and Richardson 1953) have shown that on the surface the Florida Current and Gulf Stream fronts are discontinuous. Using the Stommel-Parson airborne radiation thermometer they found that surface temperature gradients associated with the front diminished in a downstream direction to the point where they could no longer be detected, but that by turning to the left a fresh gradient could be found which in its turn would fade out. These three cross-sections suggest that these discontinuities are not merely surface phenomena but that the Gulf Stream is discontinuous at all levels all the way across its width. More accurate direct current measurements are necessary to determine to what extent the velocity pattern is a part of these discontinuities in the pressure field.

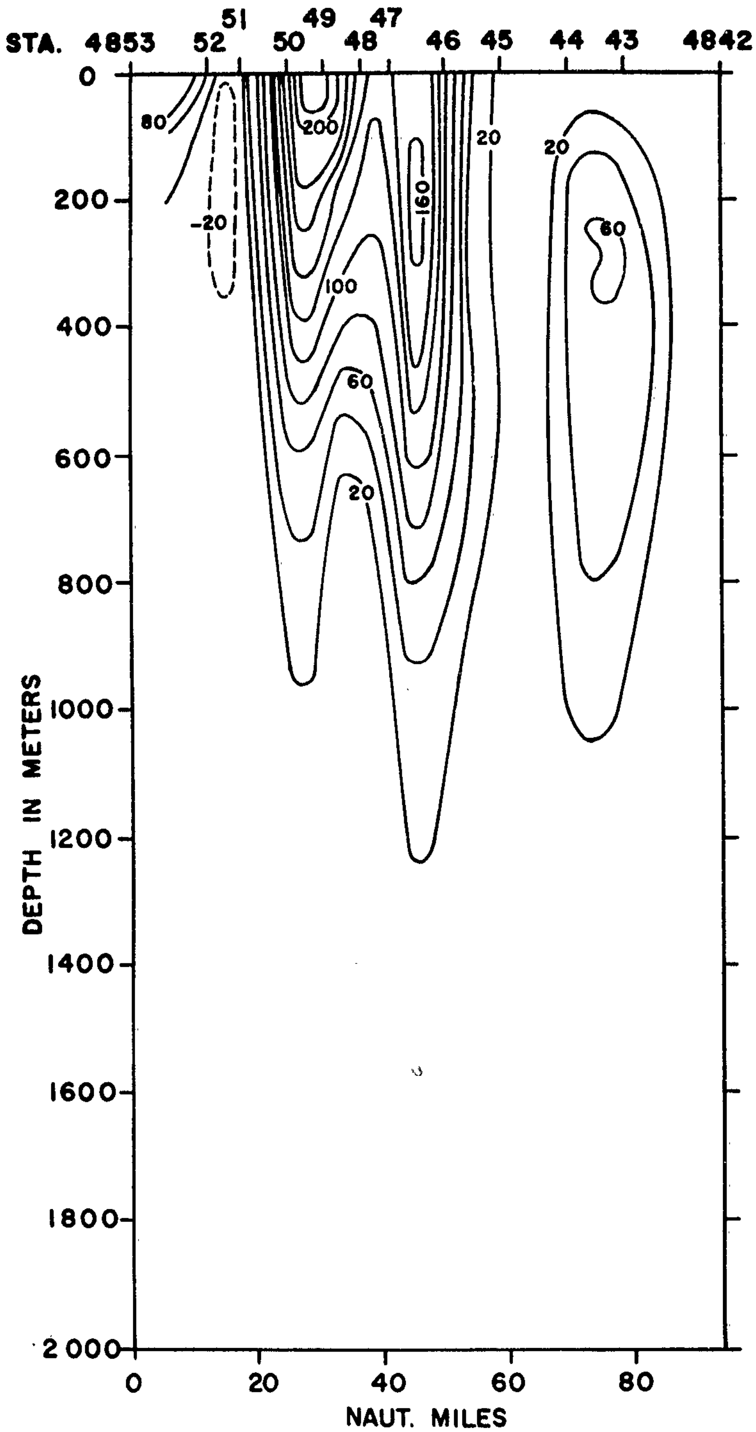

FIG. 9 SECTION I — VELOCITY CM / SEC.

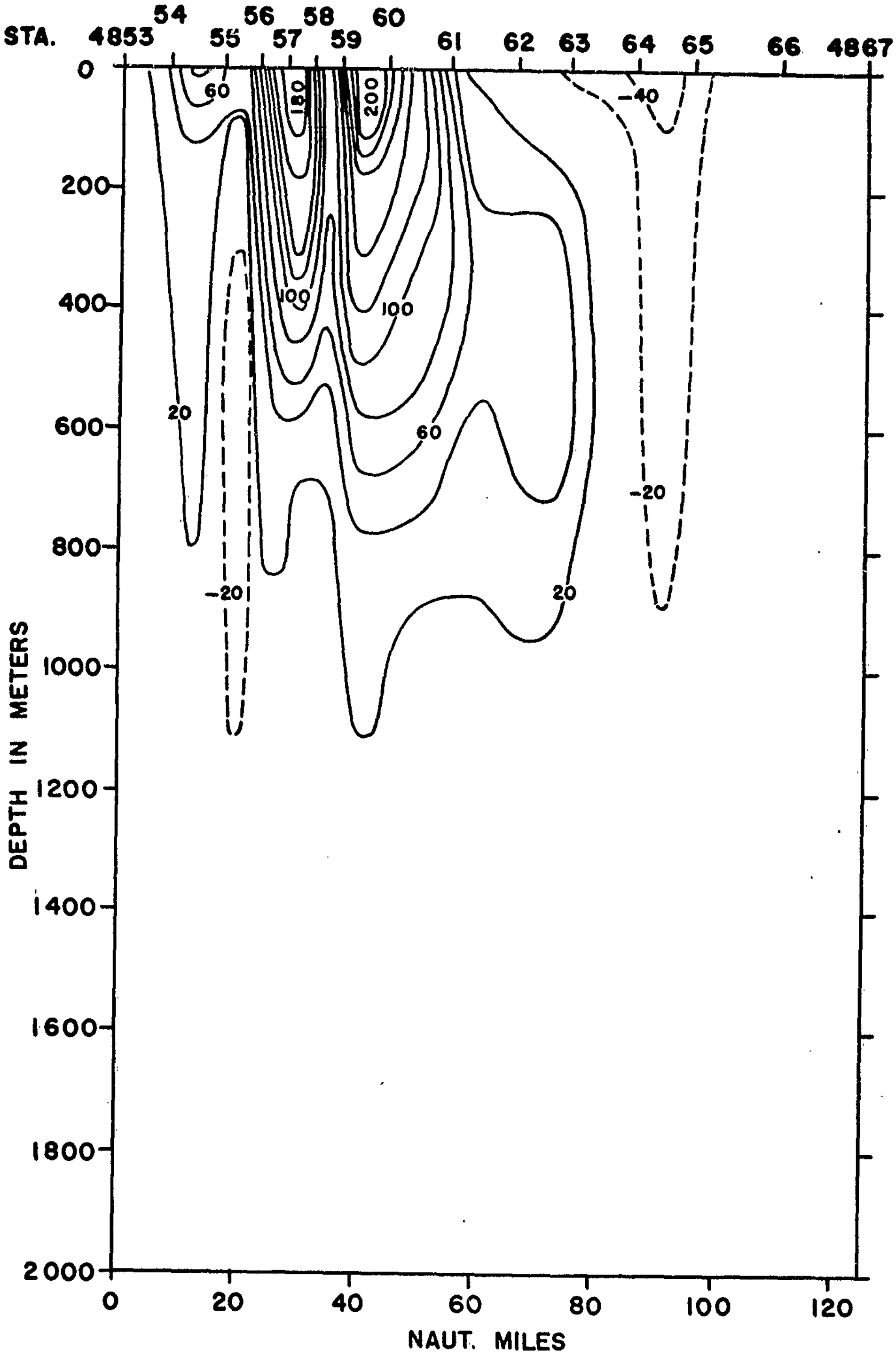

FIG. 10 SECTION 2 — VELOCITY CM / SEC.

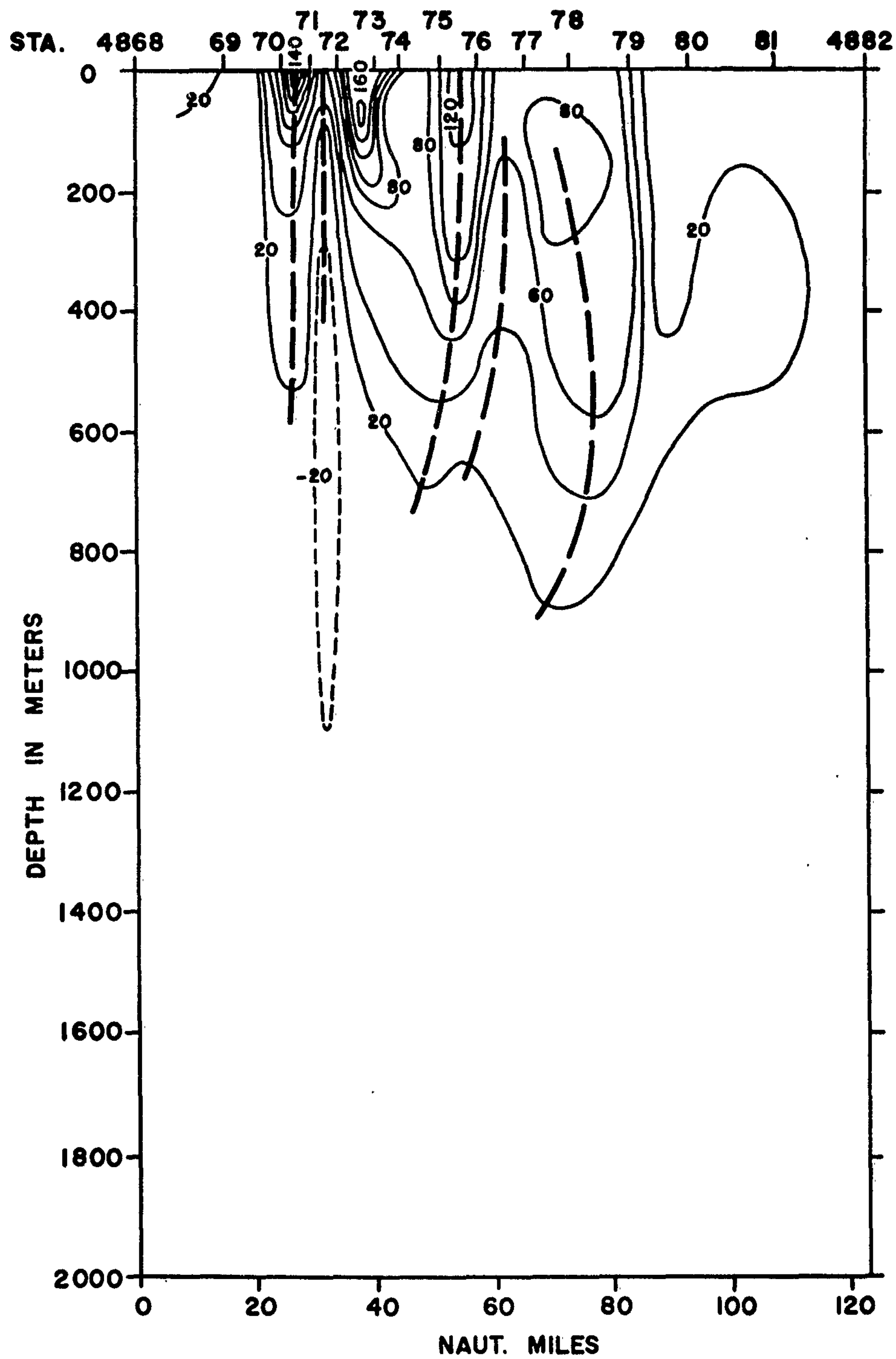

FIG. 11 SECTION 3 - VELOCITY CM / SEC.

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